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LA-UR--89-3382

DE90 002392

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SUBMITTED TO

presented to the IEEE 13th Symposium on Fusion Engineering, Knoxville, TN, October 2-6, 1989

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DESIGN AND CONSTRUCTION STATUS OF THE ENERGY SYSTEM FOR THE ZTH EXPERIMENT †

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Abstract

A large scale reversed-field pinch fusion experiment, called ZTH, is being designed and built at Los Alamos. Initially, the machine will be operating at a 1.7 MA plasma current, however, the machine can be upgraded to a 4 MA current with many of the components, such as the torus, coil system and electrical power source already having the 4 MA capability. The first plasma discharges are expected to take place in the spring of 1993. Major electrical power equipment components, such as a 1430 MVA generator, controlled power supplies, isolation and opening switches, current interrupter, capacitor banks and transfer resistor are being designed and procured for this experiment. The design philosophy of the electrical system is explained. Test results of in-house research are described and the procurement status of the major components are summarized.

1. Introduction

Los Alamos National Laboratory (LANL) is building the Confinement Physics Research Facility (CPRF) for the Office of Fusion Energy of the US Department of Energy. The first experiment in the CPRF will be a reversed field pinch device, called ZTH, whose plasma current in initial operation will be limited by the rating of the power supplies to 1.7 MA. Many components of CPRF such as the torus, the coils and the power source are designed to support higher plasma currents. A plasma current of 4 MA can be achieved with the addition of power supplies.

The electrical energy system for CPRF/ZTH consists of a pulsed generator, an ac distribution system, controlled power supplies for the toroidal field, ohmic heating and equilibrium field coils, isolation and opening switches, a capacitor bank, a transfer resistor and other electrical equipment.

In a previous paper the preliminary design of the energy system for the ZTH experiment was described [1]. In this paper progress in the design, changes in the design philosophy, and procurement status of different components and systems are summarized.

2. Pulsed Generator

LANL has acquired a 1430 MVA surplus synchronous generator and transported the components, including a 451 t stator and a 234 t rotor to Los Alamos [2]. The machine is being installed and is scheduled to be commissioned by early summer 1990 [3]. The 24 kV generator will operate at a maximum speed of 1800 rpm. About 600 MJ can be extracted in the 1800 to 1260 rpm speed range. An 8000 hp (6 MW) load commutated inverter will accelerate the machine from standstill and between pulses. A solid state excitation system, connected to LANL's 13.4 kV utility system, has enough overvoltage capability that the generator output voltage can be kept nearly constant during the load pulse. The generator is being installed with provision for a 2800 MJ flywheel (1400 MJ extractable energy) in the future. The flywheel is not necessary for a 4 MA ZTH experiment.

† Work performed under the auspices of the US DOE

3. AC Distribution System

Different options for the interface between the generator and the power conversion equipment have been investigated. A cost effective way to tie the generator to the power supplies will be by means of a current limiting fuse (CLF). LANL has contacted current limiting fuse manufacturers and identified several companies with sufficient expertise to build a fuse for our application. The fuse will trip currents in excess of 40 kA. The peak let-through current is expected to be 80 kA, which is about one quarter of the peak short circuit current. An advantage of the CLF over a conventional circuit breaker is that the ac bus can be designed electrically and mechanically for a lower current, and an open aluminum bus system or a cable connection between the generator terminals and the power supply building can be used. Line reactors for limiting the short circuit current can be eliminated, thus providing a stiffer power source.

An SF_6 breaker with 40 kA interrupting capability will be placed in series with the CLF to interrupt overcurrents up to 40 kA. The output of the SF_6 breaker is connected to the variable frequency bus. Major power supplies are connected to the variable frequency bus by vacuum circuit breakers. Only the SF_6 breaker will be closed before and opened after each plasma discharge. The specification for the CLF is being written and bid responses are expected to be evaluated by the end of 1989.

4. Poloidal Field Energy System Overview

4.1 Overview. Operation of the ZTH at 1.7 MA can be achieved with the circuit shown in Fig. 1. Initial operation at 1.7 MA and a risetime of 200 ms will allow us to reduce the number of dc current interrupting switches from four to one. Three main ohmic heating power supplies (PS1, PS2, PS3) will provide the coil charging current. The voltage and current rating of each 12-pulse supply is 12.5 kA and 3 kV full load voltage. Six 12-pulse equilibrium supplies will be installed, each having a rating of 2.5 kA and 1.2 kV full load voltage. One 50 kV, 50 kA dc current interrupter will initiate the plasma. All coil terminals and power supply terminals will be connected to a patch panel, allowing different circuit options and future component addition, such as insertion of a second dc current interrupter to double the voltage for plasma initiation. A selective relaying system will be installed, so that fault currents in the converter are interrupted by the vacuum breaker, and transformer faults by the CLF or SF_6 breaker.

4.2 Converters. The specification for the 12 pulse ohmic heating (OH) supplies have been written. LANL will initially buy three 12.5 kA, 3 kV full load voltage OH supplies, with an option for a fourth one. The converters will operate in parallel during charging of the coils and in series during flat top operation. The OH supplies will consist of a 24 kV vacuum breaker, a dry type transformer and the two 6 pulse series connected SCR bridges.

For the acquisition of the six 12 pulse equilibrium supplies we are presently pursuing two options. One option is the purchase of

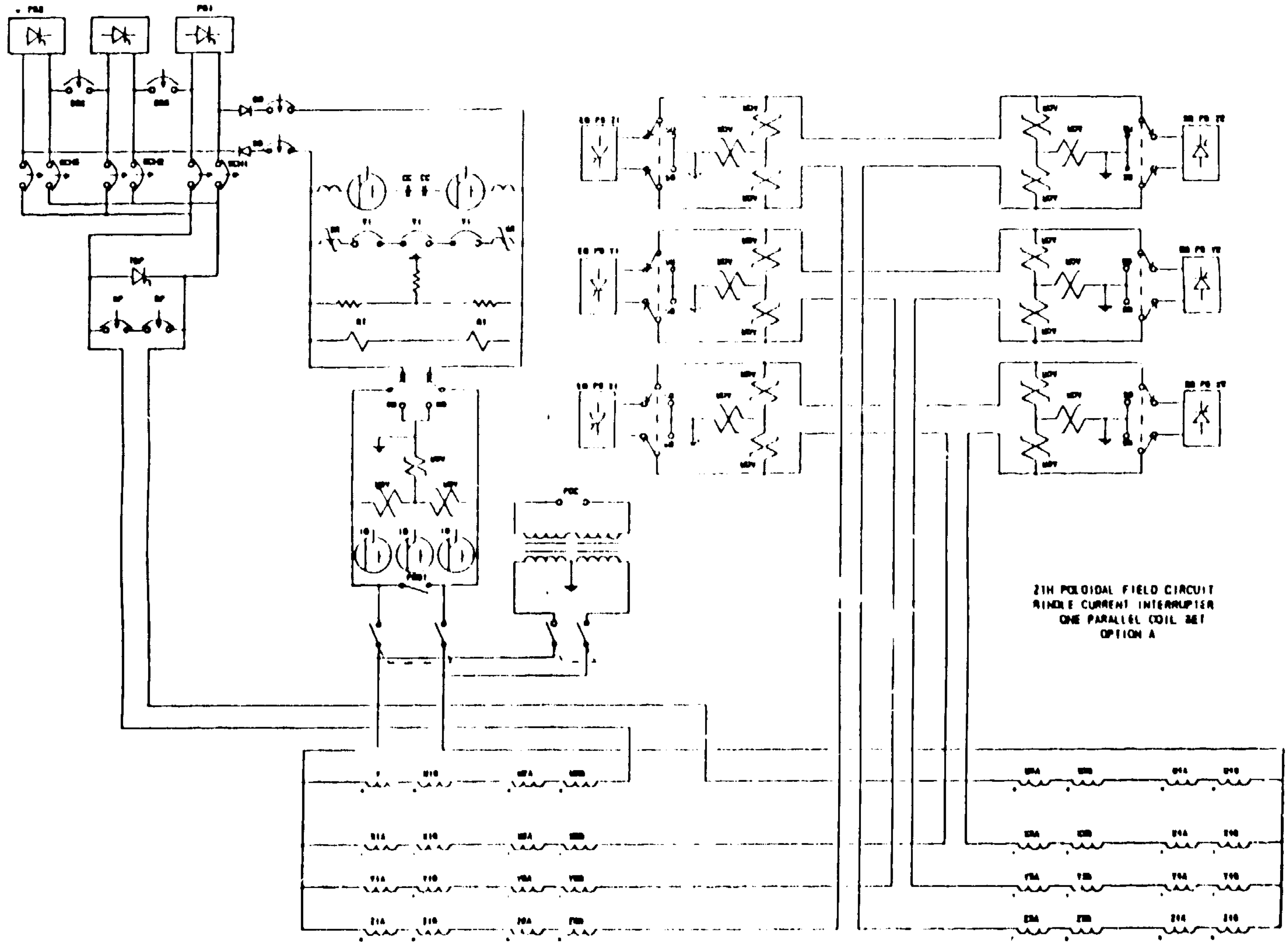

Fig. 1. ZTH poloidal field circuit.

surplus supplies and their modification for our application, while the other option is the purchase of new supplies. Purely economical reasons will be the deciding factor between the options.

4.3 Switches. A great number of isolation, disconnect, metal-to-metal and grounding switches are required for proper operation of the poloidal field energy system. For the 25 kV, 12.5 kA, and 25 kV, 50 kA isolation switches LANL initially thought that commercially available 13.8 kV vacuum interrupters would be used. We tested two vacuum breakers of two different manufacturers for 1000 shots at 50 kA, and an I^2t rating of $5 \times 10^9 A^2s$. Both switches passed the tests, however, the cost of the switches made us pursue the development of a mechanically simpler switch [4]. This air-driven switch, which was also successfully tested for 1,500 shots at 50 kA and its mechanism for 65,000 shots, will be used as an isolation switch in both a 12.5 kA and a 50 kA version.

4.4 Current Interrupters. The development of a 50 kV, 50 kA dc current interrupter started with two 13.8 kV, 1200 A commercially available vacuum interrupters in parallel. Over 100 interruptions at 50 kV/50 kA were accomplished with good current sharing in the two parallel branches. In the meantime, a heavier duty ac vacuum interrupter has been developed (13.8 kV, 3150 A) and was installed in LANL's new test facility in lieu of the two parallel breakers. This breaker was subjected to over 1,000 shots with the I^2t loading to be expected for ZTH (2.5×10^9 A^2s) provided from a 50 kA battery bank [5,6]. A similar, complementary development program of a 50 kA, 35 kV breaker using the same vacuum interrupter took place in Italy for the RFX experiment at Padua. During the course of both testing schedules the contact design of the vacuum interrupter was improved. LANL also developed the appropriate digital instrumentation for the dc current interrupter to monitor each interruption. This instrumentation is helpful by giving parameter trends, thus indicating when vacuum bottles or mechanical linkages must be replaced.

4.5 Transfer Resistor. A stainless steel, low inductance, water cooled, linear transfer resistor was ordered. The resistor has a 50 kV (± 25 kV), 50 kA, 130 MJ (180 MJ under fault conditions) rating. The transfer resistor uses 24 identical resistance modules. By connecting modules in parallel and series, ten different resistance values, about evenly spaced, can be obtained between 0.4 and 4 Ω. Delivery of the transfer resistor is scheduled for February 1990.

4.6 Equilibrium Feedback Control System. An equilibrium feedback control algorithm has been designed for controlling the six independent 12 pulse equilibrium power supplies. The operation of the entire system has been simulated by a program which models the plasma, shell, liner, coils and power supplies. The simulations show that even with a total feedback delay of 300 microseconds, the specified maximum flux surface deviation of 5 mm can be met.

The algorithm calculates correction currents for each of the equilibrium field (EF) coils from a set of input signals derived from

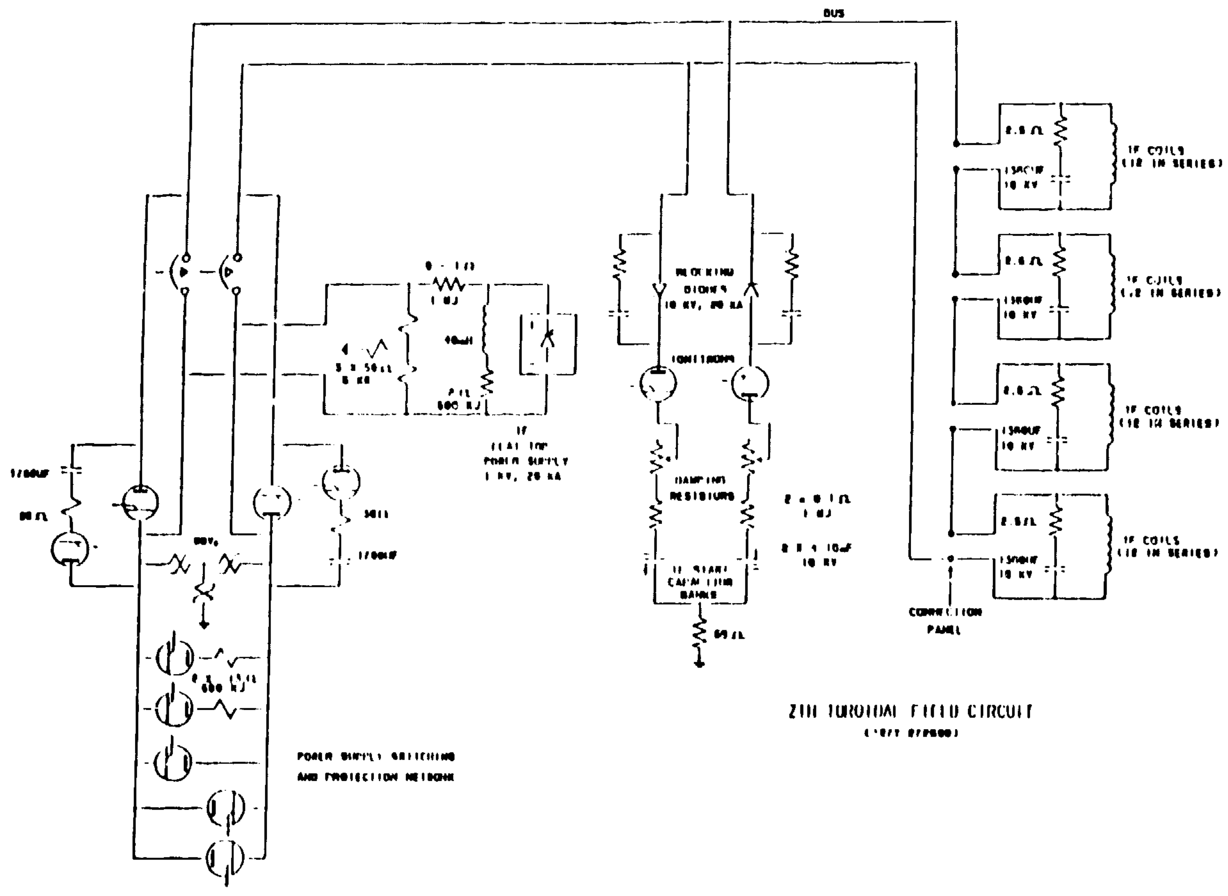

Fig. 2. ZTH toroidal field circuit.

magnetic probes located between the liner and the shell, and from current measurements in each EF and OH coil. The input signals are filtered and converted to axisymmetric Fourier modes 1 through 4. The mode signals are then multiplied by a corrector matrix to obtain the correction amplitudes. The corrector matrix is obtained by first inverting the coefficients relating flux at the plasma surface to the EF coil currents, and then weighting the result to minimize the power required to force a correction. Standard nonlinear PID signal processing is used to improve response time and accuracy.

The equilibrium controller algorithm can be implemented in either analog or digital circuitry. While an analog circuit can be much faster than a digital one, a digital system can be more versatile, reliable, and less expensive. A Motorola model 188 RISC (Reduced Instruction Set Computer) has been purchased for evaluation. Its response time of less than 70 microseconds to complete the required calculations should be sufficient to meet the system performance specification.

5. Toroidal Field Circuit

The design of the toroidal field (TF) circuit has been completed. The major circuit components are shown in Fig. 2. The design uses a small toroidal field capacitor bank that constrains ZTH to operate in fast reversal mode, as previously explained in Ref. [1]. Blocking diodes have been added to previous designs to disconnect the TF capacitor bank from the circuit at the time of current reversal, so that the TF flat-top power supplies can better control the coil current at low current levels. A patch panel is included in the design so that several connection combinations of TF coils can be investigated. The protection circuit for the TF flat top power supply includes ignitrons in various combinations, so that the proper polarity is always available to provide protection.

Components for the TF circuit are being assembled. The coil snubber, damping resistors, shunt inductor and ignitron trigger chassis have been built. LANL will use an existing 13.75 MW steady state power supply as the flat top supply. Modifications have to be made to this supply for use in the TF circuit, which include the variable frequency triggering logic (60 to 42 Hz) and changing the bus from a series bridge arrangement to a parallel arrangement. The flat top supply will provide 20 kA at 1 kV output voltage. The 24 kV pulsed transformer and the interphase reactor, needed for the parallel bridge operation, will be bought separately.

A bench-top model of the total TF circuit was built to test control feedback circuitry. The current and voltage waveshapes of critical parameters obtained from the bench top model matched previously obtained digital simulation results.

6. Summary

Major components of the energy system for the ZTH experiment have been designed and are being purchased. A 1430 MVA synchronous generator is being installed and should be operational by the summer of 1990. A 50 kV, 50 kA dc current interrupter and a 50 kV, 50 kA isolation switch has been developed and tested. The 130 MJ transfer resistor has been purchased. Components for the toroidal field circuit are being manufactured. A reduced instruction set microprocessor has been acquired to be used as the equilibrium feedback controller.

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